

PCTWORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : H02J 7/00	A1	(11) International Publication Number: WO 00/19578
		(43) International Publication Date: 6 April 2000 (06.04.00)

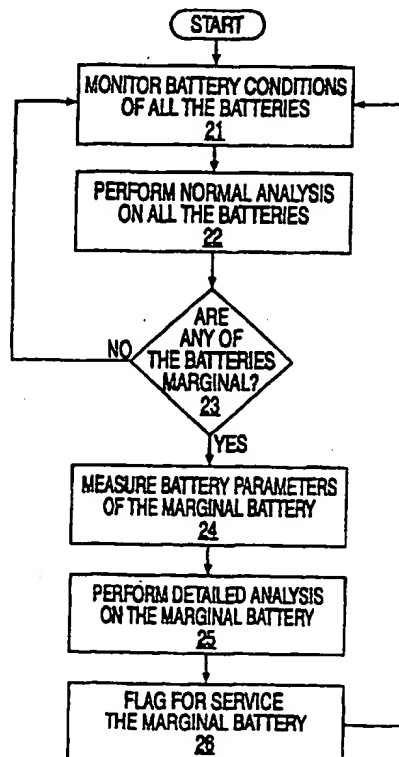
(21) International Application Number: **PCT/US99/22962**(22) International Filing Date: **1 October 1999 (01.10.99)**

(30) Priority Data:

60/102,629**1 October 1998 (01.10.98)****US****09/408,675****30 September 1999 (30.09.99)****US**(71) Applicant: **ALLIEDSIGNAL INC. [US/US]; 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US),**(72) Inventors: **MAIO, Stephen, T.; 25 Kingsbrook Court, Mendham, NJ 07945 (US). PALANISAMY, Thirumalai, G.; 14 Canterbury Way, Morristown, NJ 07960 (US). SINGH, Harman; 35 Sherbrook Drive, Rockaway, NJ 07866 (US). TEGGE, Rainer; 6 Thoresen Road, Warren, NJ 07059 (US).**(74) Agents: **CRISS, Roger, H. et al.; AlliedSignal Inc., (Law Dept., Attn: A. Olinger), 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US).**(81) Designated States: **AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).****Published***With international search report.**Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.*(54) Title: **METHOD AND APPARATUS FOR MONITORING AND MAINTAINING A PLURALITY OF BATTERIES USING A FUZZY LOGIC**

(57) Abstract

A method and apparatus for monitoring and maintaining a plurality of batteries. The batteries are maintained according to a two-part method, described in the fuzzy logic of the figure. In the first part, a normal analysis is performed on all of the batteries (22), and it is determined if any one of the batteries has marginal conditions (23). The marginal battery (which can be one or more batteries) is selected for a second part of the method, which includes a detailed analysis (24). The detailed analysis is performed on the marginal battery (25). The marginal battery is then serviced according to the results of the detailed analysis (26).



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Ireland	MX	Mexico	UZ	Uzbekistan
CA	Canada	IT	Italy	NE	Niger	VN	Viet Nam
CF	Central African Republic	JP	Japan	NL	Netherlands	YU	Yugoslavia
CG	Congo	KE	Kenya	NO	Norway	ZW	Zimbabwe
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand		
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

METHOD AND APPARATUS FOR MONITORING AND MAINTAINING A PLURALITY OF BATTERIES USING A FUZZY LOGIC

5

RELATED APPLICATION

10 The present application claims the priority of U.S. Provisional Application 60/102,629, entitled METHOD AND APPARATUS FOR MONITORING AND MAINTAINING A PLURALITY OF BATTERIES filed on October 1, 1998, the entirety of which is hereby incorporated by reference.

15 **FIELD OF THE INVENTION**

 The present invention relates generally to electrical batteries, and in particular, a method and apparatus for monitoring and maintaining batteries.

20 **BACKGROUND OF THE INVENTION**

 A battery is a device that converts the chemical energy contained in its active materials directly into electrical energy by means of an oxidation-reduction electrochemical reaction. This type of reaction involves the transfer of electrons from one material to another. Batteries in
25 the art commonly utilize electrochemical operations to store and release electrical energy.

Figure 1 illustrates the electrochemical operation of a typical battery. Referring to the figure, the negative electrode (anode 2) is the component capable of giving up electrons, being oxidized during the reaction. It is separated from the oxidizing material, which is the positive electrode (cathode 1), the component capable of accepting electrons. The transfer of electrons takes place in the external electric circuit 11 which connects the two materials 1, 2 while the electrolyte 3 provides an ionic medium for the electron transfer in the battery 4.

Because of the electrochemical nature of batteries, they are degradable products and deteriorate as a result of chemical actions that proceed during storage. Proper maintenance is critical to the operation and functional stability of batteries. There is a general need in the art for maximizing the functional stability of batteries by optimally storing and maintaining batteries. The present invention satisfies this need and others.

SUMMARY OF THE INVENTION

The invention provides a method and apparatus by which the operational characteristics of individual batteries are diagnosed. In a first preferred embodiment, a two-part method for maintaining a plurality of batteries is provided. The method comprises a first part of a normal analysis and a second part of a more detailed analysis. Initially, conditions of the batteries are monitored. The normal analysis is performed on the batteries using the battery conditions monitored. As a result of the normal analysis, the battery detected as marginal is selected. In the second part of

the method, additional battery parameters of the marginal battery are measured. The detailed analysis is performed on the marginal battery using the additional battery parameters measured. According to the results of the detailed analysis, the marginal battery is then flagged for service.

5 According to a specific embodiment of the invention, a plurality of main batteries and a corresponding plurality of auxiliary batteries are maintained. A normal analysis is performed to determine if any one of the main batteries in the battery system is marginal. The marginal battery is disconnected and a corresponding auxiliary battery is switched on. A
10 detailed analysis is then performed on the marginal battery. The marginal battery is serviced according to the results of the detailed analysis and is available for use in the battery system.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Other features and advantages of the invention will be apparent from the following Detailed Description when read in conjunction with the accompanying Drawings, in which like reference designations represent like features throughout the enumerated Figures. The Drawings referred to herein will be understood as not being drawn to scale except if
20 specifically noted, the emphasis instead being placed upon illustrating the principles of the invention. In the accompanying drawings:

Figure 1 illustrates the operation of a conventional electrochemical battery;

Figure 2 is a flow diagram illustrating a method in accordance
25 with the invention;

Figures 2A and 2B are flow diagrams illustrating a preferred embodiment of the method of the invention;

Figure 2C is a graph illustrating the relationship between the ambient temperature and the internal resistance of a battery;

5 Figure 3 is a flow diagram illustrating a specific embodiment of the method of Figure 2 for an uninterruptible power/generator system (UPS) having main and auxiliary batteries;

Figure 4 is a block diagram generally illustrating the system of the invention; and

10 Figure 5 is a block diagram illustrating a particular application of the invention as embodied in an uninterruptible power/generator system (UPS) having main and auxiliary batteries.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 Figure 2 is a flow diagram illustrating the method of the invention. Referring to Figure 2, battery conditions of all of the batteries are monitored in Step 21, including conditions from which a determination can be made whether a particular battery is marginal. A normal analysis is performed on all the batteries (Step 22). A "normal analysis" monitors
20 sufficient battery conditions to determine whether a battery is marginal. A "marginal" battery has conditions outside of a prescribed range of suitable values for the intended purpose of the battery. Step 23 determines whether any one of the batteries is marginal. If none of the batteries has marginal battery conditions, then the control flow is reverted to Step 21
25 and the conditions of the batteries continue to be monitored.

On the other hand, if a battery is determined to be marginal, additional battery parameters of the marginal battery are measured (Step 24) for use in a detailed analysis of that battery (Step 25). Among the additional battery parameters that are measured are the state of charge, electrolyte level, terminal resistance, and battery capacity. The detailed analysis includes analyzing the battery parameters measured to determine the actions required to service the marginal battery. The marginal battery then can be serviced according to the results of the detailed analysis (Step 26). The purpose of the battery servicing is to ensure that the battery operates above marginal condition. In the meantime, the conditions of all the batteries are continuously monitored.

The invention provides a two-part method for maintaining the plurality of batteries comprising a normal analysis followed by a detailed analysis, if necessary. The normal analysis is applied to all batteries during normal operation of the battery system. The detailed analysis is selectively performed on specific batteries based on the results of the normal analysis. Upon detection of marginal batteries among the plurality of batteries, the detailed analysis is performed on the marginal batteries individually. The detailed analysis can also be performed offline or during system down time.

Figures 2A and 2B are flow diagrams illustrating a preferred embodiment of the method of the invention. The steps taken to perform the normal analysis and the detailed analysis can be implemented in hardware or software.

Referring to Figure 2A, some battery conditions, such as voltage, current and temperature conditions, are monitored for each of the

plurality of batteries in Step 221 while others are derived from such measurements. The normal analysis on such battery conditions is performed at Step 223 and includes an analysis of:

- (1) Battery terminal voltage;
- 5 (2) Battery terminal voltage behavior in response to load variation;
- (3) Charge and discharge current; and
- (4) Battery ambient temperature.

Using the measured voltage, current and temperature data, the
10 internal resistance (IR) and the state of charge (SOC) of a battery can be determined as part of the normal analysis of Step 223. A battery is deemed marginal if any one of its voltage, current and temperature measurements significantly deviates from a prescribed range and/or the rest of the batteries. A battery is also deemed marginal if it has faulty
15 conditions, such as a low SOC or high IR (Step 225). Adjustment can then be made with respect to any marginal battery at Step 228. Any marginal batteries are reported (Step 227) and actions are recommended for the affected battery (Step 229). For example, if a low SOC is detected, which is considered a faulty condition, the low SOC level is reported (Step 227).
20 An action to remedy the low SOC, such as increasing the voltage charge supplied to the marginal battery, or performing a detailed analysis on the marginal battery (Step A), can be recommended (Step 229).

Faulty conditions of the batteries can also be anticipated at Step 225 before they occur. The occurrence and timing of a faulty
25 condition are anticipated by determinations that are made during the course

of the normal analysis. For example, a maximum IR limit can be set for each battery and its occurrence anticipated based on the voltage, current and temperature measurements for that battery. In particular, the IR is computed as the measured voltage divided by the measured current and this value can be plotted against the temperature. See Figure 2C. Preferably, the maximum IR limit is set as one the fault conditions to be detected at Step 225. If no fault condition is detected, then the maximum IR limit optionally can be adjusted at Step 228 in view of the voltage, current and temperature measurements of the normal analysis of Step 223.

10 In the meantime, battery conditions of all of the batteries are continuously monitored.

In a specific embodiment, a plurality of batteries is monitored and each one's IR is determined. Measurements are made at predetermined intervals by monitoring the voltage, current and temperature conditions for each battery. The IR and SOC of each battery, together with the temperature, are then used to determine whether the battery condition is marginal or not. The IR is calculated at a given temperature based on these data, and the basic IR vs. temperature curve can be reconstructed based on calculated IR over the temperature range for the present SOC of the battery. Once the IR vs. temperature curve is obtained from the measured data it is compared with a standard curve of IR vs. temperature based on the requirements of the system. Using this IR limit analysis, battery useful life can be predicted at Step 225 and servicing actions anticipated and reported at Step 227.

Figure 2C depicts the battery IR and the maximum allowable limit of IR as a function of temperature for a typical battery. Such a graph is found in the specifications of most commercially available batteries. The measured IR of a given battery is compared with the maximum allowed by the IR limit curve for that battery or battery type. Based on the temperature conditions being monitored, extrapolations can be made for both the ambient temperature and IR so that the time when a battery will exceed its IR limit can be anticipated. Based on the anticipated information, operational time periods can be anticipated and offline times can be scheduled for individual batteries for servicing. Adjustments are made according to the forecast information at Step 228 of Figure 2A. Meanwhile, the conditions of all the batteries are monitored on a continuous basis.

Once a marginal battery has been detected, the detailed analysis is performed, as described next. The process of Figure 2B flows from Step 229 of Figure 2A. At Step 231, a load is applied to the marginal battery so that additional battery parameters can be measured at Step 233 for the marginal battery. The additional battery parameters include the SOC, electrolyte level, terminal resistance, and battery capacity. The additional battery parameters are used in the detailed analysis step, Step 235, to determine the following:

- (1) Mismatched cells, *e.g.*, individual cells within the battery that may be at different capacity levels;

- (3) Soft-shortcd cells, often found in lead-acid batteries, where the shorted cell behaves like a normal cell with low capacity during charge, but becomes a dead cell and loses voltage during discharge and in long open circuit periods;
- (4) Reverse connections (during initial installations), where the positive terminal of a battery is connected to a negative terminal of the charger, and the negative terminal of the battery is connected to the positive terminal of the charger;
- (5) High terminal resistance, which leads to a substantial voltage drop that reduces the power available for use in the system;
- (6) Low electrolyte level, which causes non-uniformity in electrolyte concentration and negatively affects ionic transfer;
- (7) Corroded terminals, which lead to a substantial increase in resistance at the terminal-to-wire connections.
- (8) Battery status, such as:
- Battery capacity,
 - Electrolyte adequacy, and
 - State of charge (SOC);
- (8) Time to maintain/replace individual batteries, such as the end of a battery's useful life; and

(9) Current or voltage ramp test.

For example, a current or voltage ramp test provides a profile of current or voltage over increasing applied current or voltage (ramp up) and over decreasing applied current or voltage (ramp down) directions. The SOC is
5 determined of the marginal battery from the current during the ramp down portion of the test. Battery capacity is derived from the SOC.

The results of the detailed analysis are reported and actions are recommended at Step 237. For example, a marginal battery affected with a faulty condition can be replaced, *e.g.*, by switching to another
10 battery. If a reverse connection was detected in Step 235, the condition is reported (Step 237) and the reverse connection is rectified manually. Likewise, if a low electrolyte level was detected, the condition is reported and electrolyte is added. If it is time to maintain or replace the marginal battery, *e.g.*, because the maximum IR limit is reached, the marginal battery
15 is disconnected for servicing or replacement. Alternatively, if a high terminal resistance or corroded terminal condition were detected, such conditions would be reported and the affected battery disconnected for servicing (*e.g.*, terminal cleaning). The battery power shortfall while the marginal battery is disconnected can be supplanted by switching on another
20 battery, that is, an auxiliary battery. If inadequate state of charge (SOC) was detected, then a determination is made whether the marginal battery can be taken offline by shutting down the battery system in Step 239. If the marginal battery cannot be taken offline, *e.g.*, the battery power being supplied by the system cannot be interrupted, then the control flows back

(via Step E) to Step 221 of Figure 2A, where battery conditions of all the batteries are continuously monitored.

If the marginal battery can be taken offline, then a charge/discharge cycle is performed and the battery capacity is detected and verified for normal operation (Step 238). The results of the charge/discharge cycle are evaluated in Step 236. If the results are within a prescribed range, the marginal battery is charged and then returned in-line for normal operation in the battery circuit. The control flow is then reverted back to Step 221 of Figure 2A, where battery conditions of all the batteries are continuously monitored.

If the results of the charge/discharge cycle are outside of a prescribed range, then the marginal battery is flagged for discarding or replacement (Step 232). The control flow is then reverted back (via Step E) to Step 221 of Figure 2A, where battery conditions of all the batteries are continuously monitored.

The method of the invention can also be applied to an uninterruptible power/generator system (UPS) having a set of main batteries and a set of auxiliary batteries. With reference now to Figure 3, the operating conditions of the main batteries are continuously monitored at Step 31. Normal analysis is performed at Step 32 and a determination is made at Step 33 as to whether any of the main batteries is marginal, substantially as described above in connection with Steps 21-23. If no marginal battery is detected, the control flow then reverts to Step 31.

On the other hand, if a marginal battery is detected, the marginal battery is disconnected (Step 34) and a corresponding auxiliary

battery is switched into the circuit to maintain battery power supply (Step 35). Additional battery parameters of the affected battery are measured at Step 36 and a detailed analysis is performed using such battery parameters measured (Step 37), substantially as described above. The marginal battery
5 is then flagged for service in accordance with the results of the detailed analysis (Step 38). The control flow then reverts to Step 31, where the conditions of the main batteries are continuously monitored.

Figure 4 is a block diagram generally illustrating a system in accordance with this embodiment of the invention. Referring to Figure 4, a
10 normal analysis controller 41 performs the normal analysis steps that were previously described. Also provided is a detailed analysis controller 43, connected to the normal analysis controller 41 and responsive to signals therefrom over line 45, which performs the detailed analysis steps described above. A plurality of batteries (BAT. 1, BAT. 2, BAT. 3, BAT. 4,
15 . . .) is connected to both the normal analysis controller 41 and the detailed analysis controller 43. The detailed analysis controller 43 can override the normal analysis controller 41 when service for any of the batteries is required.

Figure 5 is a detailed block diagram illustrating a preferred
20 application for a UPS. Referring to Figure 5, a normal analysis controller 51 is coupled to a plurality of batteries, MAIN BAT. 1-4 and AUX GEN. BAT. 1-4. The batteries used in the system are rechargeable batteries of a type commonly used in the art, such as nickel-cadmium, nickel-hydrogen, nickel-zinc, nickel-iron, silver-zinc, zinc bromine, zinc-chlorine, and lead-acid
25 batteries. The normal analysis controller 51 continuously analyzes the

prevailing battery conditions and implements maintenance and charging functions as described above. The battery conditions can be monitored when the load (such as the UPS) itself draws current from the battery bank, *e.g.*, when AUX GEN. 53 is started or when the AC power source is
5 operational. When the UPS is not providing power, the normal analysis controller 51 continues to monitor and analyze the temperature, voltage and current conditions from which it determines the IR and SOC of each battery with changes in temperature. The individual battery's IR and SOC, together with the temperature, are then used to determine whether the
10 battery condition is marginal.

The normal analysis controller 51 flags as marginal any one of the plurality of batteries which is found to have one or more faulty conditions, such as a low SOC or high IR. Any marginal or faulty conditions identified by the normal analysis controller 51 are reported to the
15 detailed analysis controller 59 for further detailed analysis.

COMM LINK 52 provides remote communication and programming capabilities for the normal analysis controller 51 and also the detailed analysis controller 59. For example, complete charge/discharge cycles can be performed by remote commands transmitted via COMM LINK
20 52 on a periodic basis, *e.g.*, once per year.

The normal analysis controller 51 is coupled to the detailed analysis controller 59, which can override the analytical and implementing functions of the normal analysis controller 51. In addition, the detailed analysis controller 59 has the ability to re-initialize the algorithms of the
25 normal analysis controller 51, depending on a diagnostic analysis or any

change in conditions. The detailed analysis controller 59 is also coupled to the fixed load 55, through a switch SW.

The detailed analysis controller 59 can override the automatic status monitoring of the normal analysis controller 51, invoke self tests, upload self test results, upload individual battery voltage, current and temperature data, perform voltage or current ramp tests, disable individual batteries, and upgrade software algorithms which are resident in the normal analysis controller 51.

For example, the detailed analysis controller 59 can perform the current or voltage ramp test as described above, with the state of charge being determined from the current in the ramp down direction. The battery capacity of the marginal battery is determined based on the state of charge.

The main battery group of MAIN BAT. 1-4 is coupled to SWITCHING SYSTEM 2. The auxiliary battery group of AUX GEN. BAT. 1-4 is coupled to SWITCHING SYSTEM 1. SWITCHING SYSTEM 1 is coupled to a auxiliary power generator AUX GEN. 53, whose output is coupled to SWITCHING SYSTEM 2. SWITCHING SYSTEM 2 is coupled to a power load module for alternating current (AC) power generation, *i.e.*, 1350W to 2000W Load Module 57.

In operating the battery system, main battery power (from MAIN. BAT. 1-4) is routed through SWITCHING SYSTEM 2 which either connects the main battery power to a load module (*i.e.*, 1350 to 2000W Load Module 57) for AC power generation or to the normal analysis controller 51 for analysis and maintenance. If any marginal batteries are

detected, SWITCHING SYSTEM 2 is commanded by the normal analysis controller 51 to isolate the affected batteries for later servicing.

The auxiliary generator battery power (generated by AUX GEN. BAT. 1-4) is also routed through a switching system (SWITCHING SYSTEM 1). SWITCHING SYSTEM 1 either connects the AUX GEN. BAT. 1-4 to the auxiliary generator (AUX. GEN.) for contingent power generation or to the normal analysis controller 51 for analysis, charging or isolation as required by the algorithms resident in the normal analysis controller 51.

The aforementioned switching systems provide flexibility and optimal performance by allowing the battery system to allocate power resources based on the conditions of each battery. For example, if a main battery is defective, or malfunction is anticipated therefor, the system can simply isolate that main battery for service and switch to an auxiliary generator battery. The auxiliary generator battery, *e.g.*, AUX GEN. BAT. 1, can then start AUX GEN. 53 as an alternative power generation source.

An exemplary operation of the system of the invention as embodied in the UPS of Figure 5 is illustrated herein. During normal operation, each battery is automatically connected to its corresponding functional power grid for immediate use. The conditions of the main batteries (MAIN BAT. 1-4) are continuously monitored. The normal analysis controller 51 performs a normal analysis on the main batteries (MAIN BAT. 1-4) using the conditions monitored. The normal analysis controller 51 determines if any of the main batteries is marginal. The fixed load 55 is automatically switched on during the normal analysis performed by the normal analysis controller 51.

If a marginal battery is detected (*e.g.*, MAIN BAT. 1), using SWITCHING SYSTEM 1 and SWITCHING SYSTEM 2 the marginal battery is disconnected and a corresponding auxiliary battery is switched on to maintain battery power supply. Thereafter, additional battery parameters of the marginal battery (MAIN BAT. 1) are measured. The detailed analysis controller 59 performs a detailed analysis on the marginal battery (MAIN BAT. 1) using such battery parameters measured. The marginal battery (MAIN BAT. 1) is then flagged for service according to the results of the detailed analysis.

10 An advantage of the invention is that charging characteristics are automatically adjusted to suit each battery, with each battery being charged with maximum efficiency and speed. According to the invention, a battery is not recharged if it is determined that it has been fully charged after analyzing its state of charge. The batteries advantageously operate at
15 peak efficiency with enhanced battery life and the inventive system and method eliminate the need for continuous charging. The advantages of the invention further include reduction in total battery cost and prolonged battery life. In addition, all testing and maintenance functions are easily reconfigurable and can be upgraded any time, by instructing the detailed
20 analysis controller to revise algorithms in the normal analysis control. The end of useful life or malfunctions of the batteries are anticipated by a trend analysis of the internal resistance (IR), battery capacity and their respective limits. The efficiency of maintaining the batteries is optimized since battery malfunctions are anticipated and battery maintenance scheduled before
25 such failures are encountered.

Thus, while there have been shown, described, and pointed out fundamental novel features of the invention as applied to a preferred embodiment thereof, it will be understood that various omissions, substitutions, and changes in the form and details of the devices illustrated, and in their operation, may be made by those skilled in the art without departing from the spirit and scope of the invention. For example, it is expressly intended that all combinations of those elements and/or steps which perform substantially the same function, in substantially the same way, to achieve the same results are within the scope of the invention.

Substitutions of elements from one described embodiment to another are also fully intended and contemplated. It is also to be understood that the drawings are not necessarily drawn to scale, but that they are merely conceptual in nature. It is the intention, therefore, to be limited only as indicated by the scope of the claims appended hereto.

WE CLAIM:

- 1 1. A two-part method for maintaining a plurality of batteries, having a
2 first part comprising a normal analysis and a second part comprising a
3 detailed analysis, the method comprising the steps of:
4 monitoring battery conditions of the plurality of batteries;
5 performing the normal analysis on the plurality of batteries using the
6 monitored battery conditions;
7 selecting at least one battery which is detected as being marginal by
8 the normal analysis;
9 measuring battery parameters of the marginal battery;
10 performing the detailed analysis on the marginal battery using the
11 measured battery parameters; and
12 flagging for service the marginal battery according to the results of
13 the detailed analysis.
- 1 2. The method of claim 1, wherein the battery conditions of the
2 plurality of batteries are monitored continuously.
- 1 3. The method of claim 1, wherein the detailed analysis overrides the
2 normal analysis.
- 1 4. The method of claim 1, further comprising the steps of:
2 selectively supplying a voltage charge to each of the batteries;
3 monitoring state of charge (SOC) of the plurality of batteries; and

4 adjusting the voltage charge according to the state of charge (SOC)
5 monitored.

1 5. The method of claim 1, further comprising the step of recommending
2 actions to service the marginal battery.

1 6. The method of claim 1, further comprising the step of increasing
2 voltage charge to the marginal battery if the marginal battery has low state
3 of charge (SOC).

1 7. The method of claim 1, wherein the conditions monitored consist of
2 battery terminal voltage, battery ambient temperature, charge and
3 discharge current.

1 8. The method of claim 1, wherein the battery parameters measured
2 consist of mismatched cells, soft-shortened cells, reverse connections, high
3 terminal resistance, low electrolyte level, corroded terminals, power system
4 status, battery capacity, state of charge, and time to maintain/replace
5 battery.

1 9. The method of claim 1, further comprising the step of determining if
2 the marginal battery can be taken offline.

1 10. The method of claim 9, further comprising the steps of:
2 performing a charge/discharge cycle on the marginal battery; and

3 verifying battery capacity of the marginal battery;
4 provided it is determined that the marginal battery can be taken
5 offline.

1 11. The method of claim 10, further comprising the step of evaluating
2 results of the charge/discharge cycle performed.

1 12. The method of claim 11, further comprising the step of charging the
2 marginal battery if the evaluated results are within a prescribed range.

1 13. The method of claim 11, further comprising the step of replacing the
2 marginal battery if the evaluated results are outside of a prescribed range.

1 14. The method of claim 1, further comprising the steps of:
2 analyzing internal resistance (IR) of the batteries; and
3 anticipating a time when the IR reaches an IR limit.

1 15. The method of claim 14, wherein useful life of the batteries is
2 predicted based on the internal resistance analysis and the IR limit.

1 16. The method of claim 1, further comprising the steps in a programmed
2 machine of:
3 determining an internal resistance (IR) versus temperature curve;
4 comparing the IR versus temperature curve with a reference IR
5 versus temperature curve; and

6 extrapolating from the comparison a time when an IR limit is reached.

1 17. A method for maintaining a plurality of main batteries and a
2 corresponding plurality of auxiliary batteries, comprising the steps of:
3 monitoring battery conditions of the plurality of main batteries;
4 performing a normal analysis on the plurality of main batteries using
5 the monitored battery conditions;
6 selecting a main battery which was detected as being marginal by
7 the normal analysis;
8 replacing the marginal main battery with an auxiliary battery;
9 measuring battery parameters of the marginal main battery;
10 performing the detailed analysis on the marginal battery using the
11 measured battery parameters; and
12 flagging for service the marginal main battery according to the results
13 of the detailed analysis.

1 18. The method of claim 17, wherein the battery conditions of the
2 plurality of main batteries are monitored continuously.

1 19. The method of claim 17, further comprising the steps of:
2 selectively supplying a voltage charge to each of the main batteries;
3 monitoring state of charge (SOC) of the plurality of main batteries;
4 and
5 adjusting the voltage charge according to the state of charge (SOC)
6 monitored.

1 20 The method of claim 17, wherein the detailed analysis overrides the
2 normal analysis based on the battery conditions monitored.

1 21. The method of claim 20, wherein the detailed analysis overrides the
2 normal analysis by a process selected from the group consisting of invoking
3 self tests, uploading self test results, uploading battery voltage, current and
4 temperature data, performing a current ramp test, performing a voltage
5 ramp test, disabling individual batteries, and upgrading software algorithms
6 in the normal analysis.

1 22. The method of claim 17, wherein the conditions monitored consist
2 of battery terminal voltage, battery ambient temperature, charge and
3 discharge current.

1 23. The method of claim 17, wherein the battery parameters measured
2 consist of mismatched cells, soft-shortened cells, reverse connections, high
3 terminal resistance, low electrolyte level, corroded terminals, power system
4 status, battery capacity, state of charge, and time to maintain/replace
5 battery.

1 24. The method of claim 17, wherein the normal analysis and the
2 detailed analysis are software implemented.

1 25. The method of claim 17, further comprising the step of applying a
2 load to the marginal battery.

- 1 26. A system for maintaining a plurality of batteries, comprising:
2 a normal analysis controller monitoring battery conditions of the
3 plurality of batteries, performing a normal analysis on the plurality of
4 batteries based on the conditions monitored, and selecting at least one
5 marginal battery based on the normal analysis; and
6 a detailed analysis controller performing a detailed analysis on the
7 marginal battery;
8 wherein the marginal battery is serviced according to results of the
9 detailed analysis.
- 1 27. The system of claim 26, wherein the battery conditions are
2 monitored continuously.
- 1 28. The system of claim 26, wherein the detailed analysis controller
2 overrides the normal analysis controller performing the normal
3 analysis on the plurality of batteries.
- 1 29. The system of claim 28, wherein the detailed analysis controller
2 overrides the normal analysis controller by a process selected from the
3 group consisting of invoking self tests, uploading self test results, uploading
4 battery voltage, current and temperature data, performing a current ramp
5 test, performing a voltage ramp test, disabling individual batteries, and
6 upgrading software algorithms in the normal analysis control.

1 30. The system of claim 26, wherein the plurality of batteries comprise a
2 plurality of main batteries and a plurality of auxiliary batteries.

1 31. The system of claim 30, further comprising a switch, wherein the
2 switch switches on one of the plurality of auxiliary batteries corresponding
3 to a marginal battery in the plurality of main batteries selected based on the
4 normal analysis.

1 32. The system of claim 26, wherein the conditions monitored consist of
2 battery terminal voltage, battery ambient temperature, charge and
3 discharge current.

1 33. The system of claim 26, wherein the battery parameters measured
2 consist of mismatched cells, soft-shortened cells, reverse connections, high
3 terminal resistance, low electrolyte level, corroded terminals, power system
4 status, battery capacity, state of charge, and time to maintain/replace
5 battery.

1 34. The system of claim 26, further comprising a communication link
2 connected to the normal analysis control, wherein the communication link
3 provides remote communication and programming capabilities.

1 35 The system of claim 34, wherein battery servicing is performed by
2 remotely sending a command to the communication link on a periodic basis.

1 36. The system of claim 34, wherein a charge/discharge cycle is
2 performed by remotely sending a command to the communication link.

1 37. The system of claim 26, wherein the batteries are rechargeable
2 batteries selected from the group of nickel-cadmium batteries, nickel-
3 hydrogen batteries, nickel-zinc batteries, nickel-iron batteries, silver-zinc
4 batteries, zinc bromine batteries, zinc-chlorine batteries, and lead-acid
5 batteries.

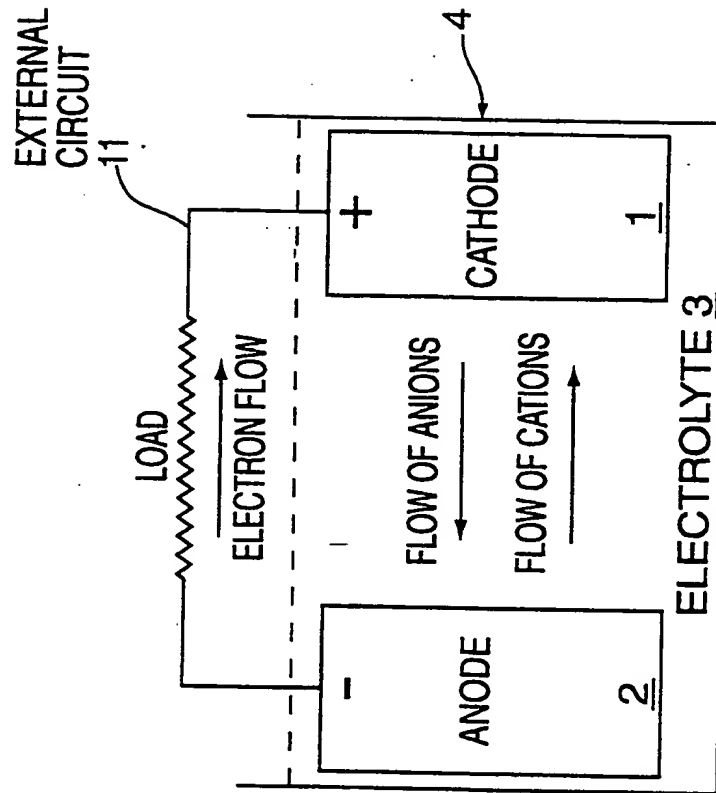


FIG. 1
(PRIOR ART)

2/8

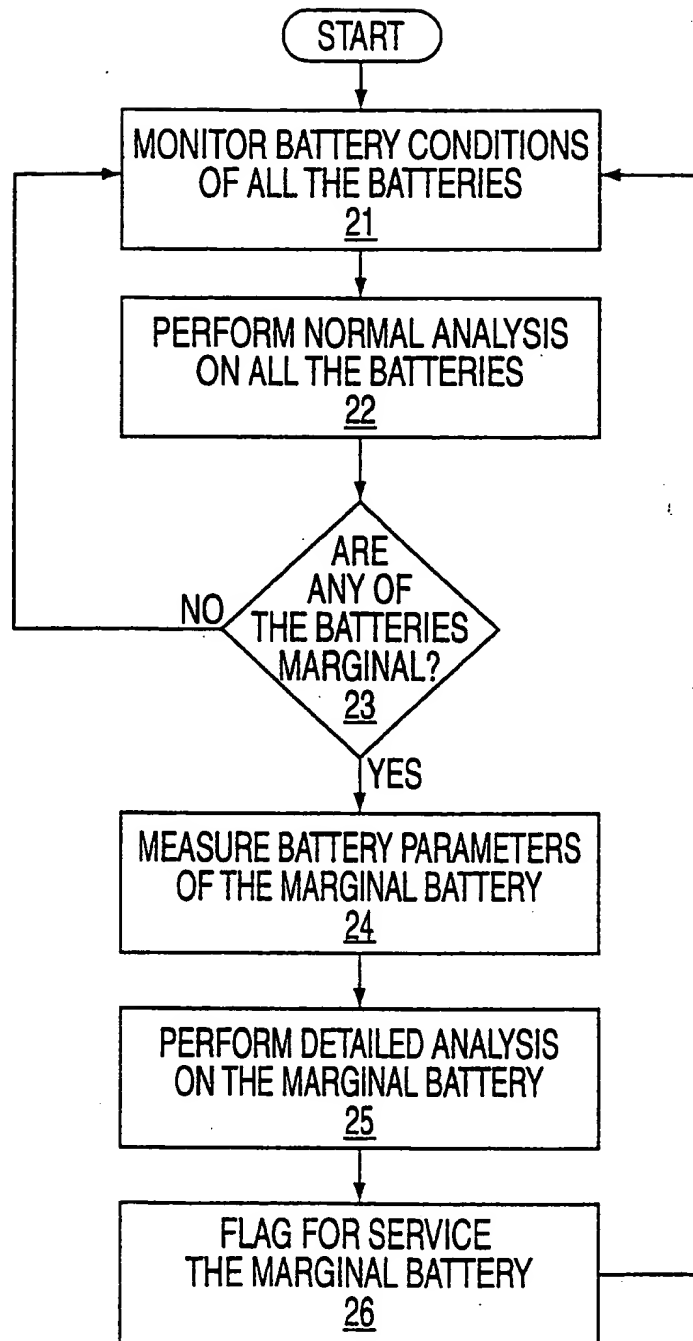


FIG. 2

3/8

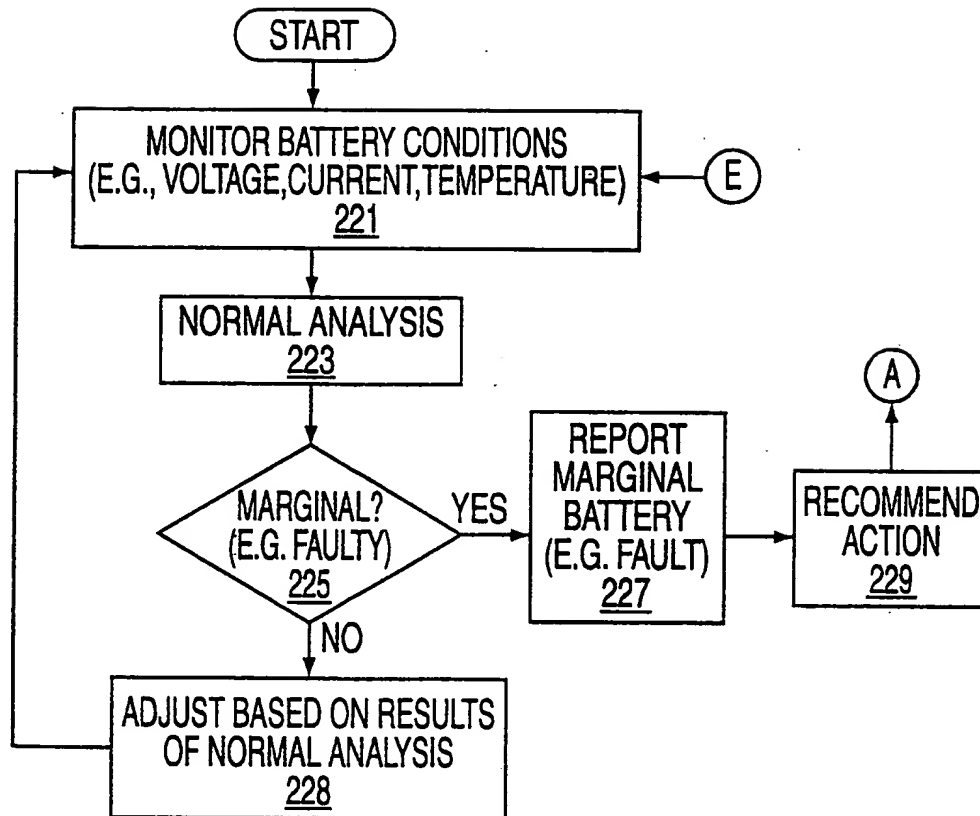


FIG. 2A

4/8

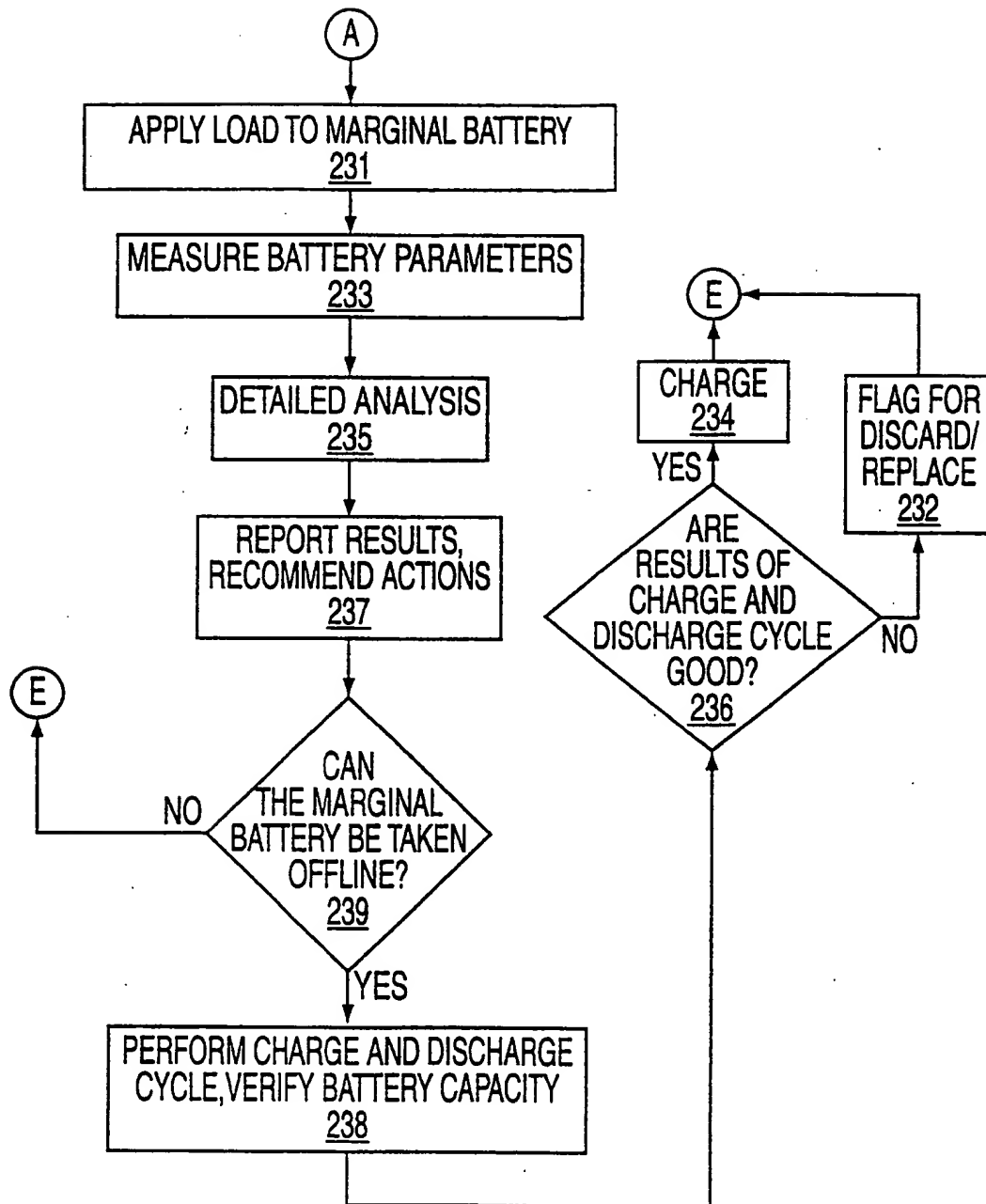
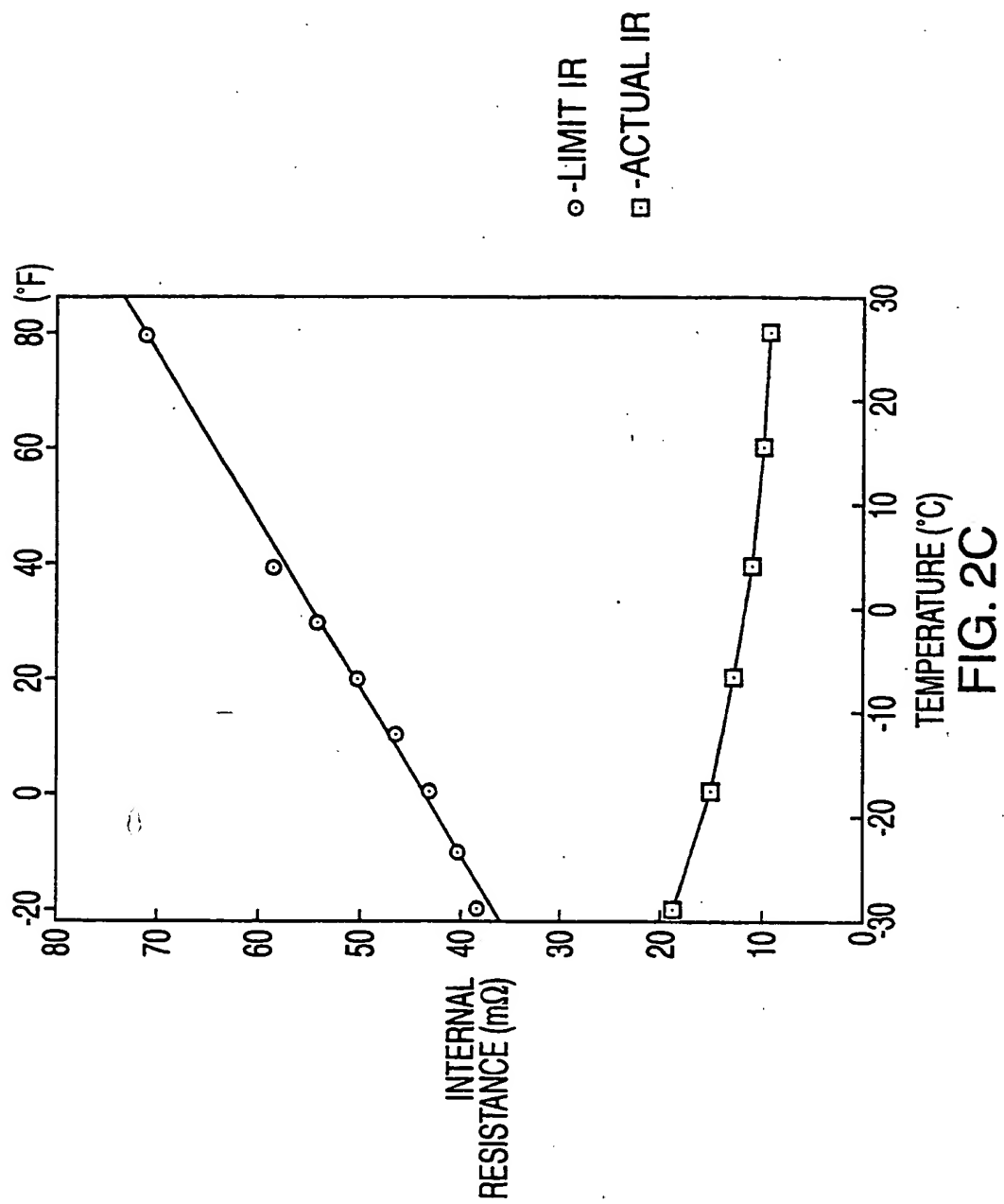


FIG. 2B

5/8



6/8

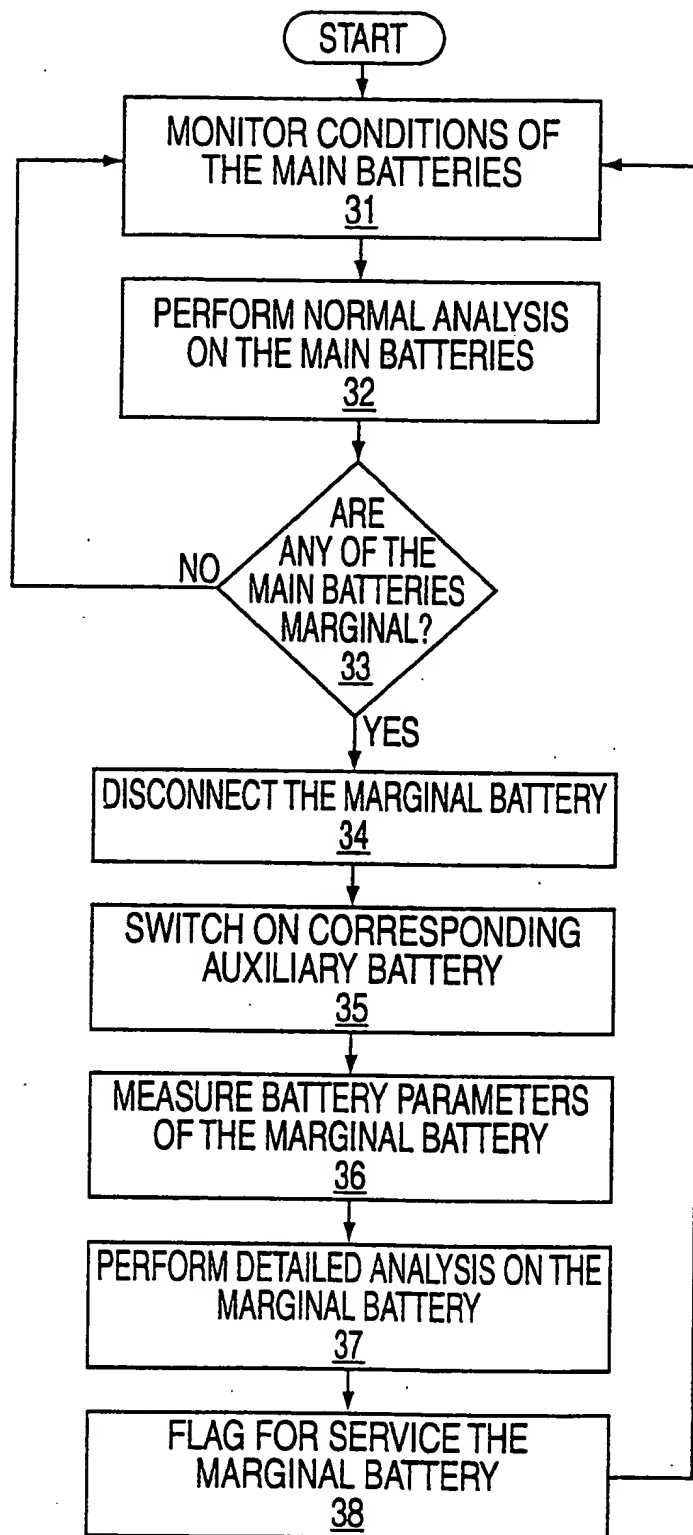


FIG. 3

7/8

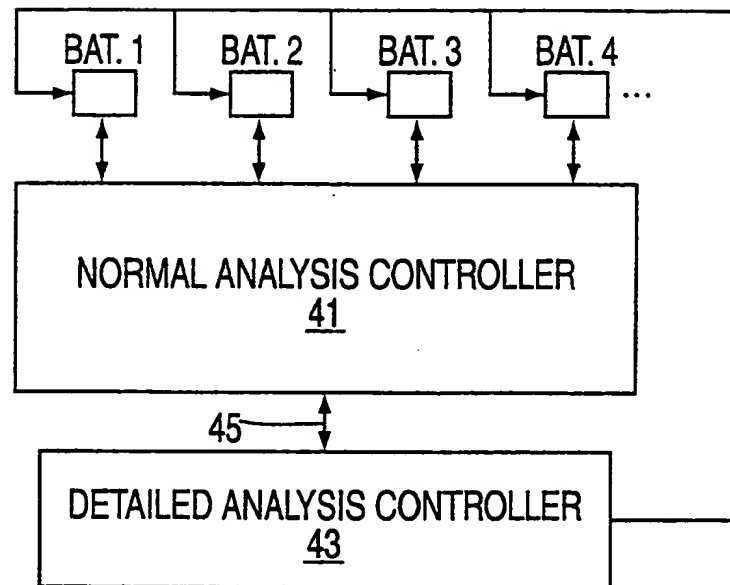
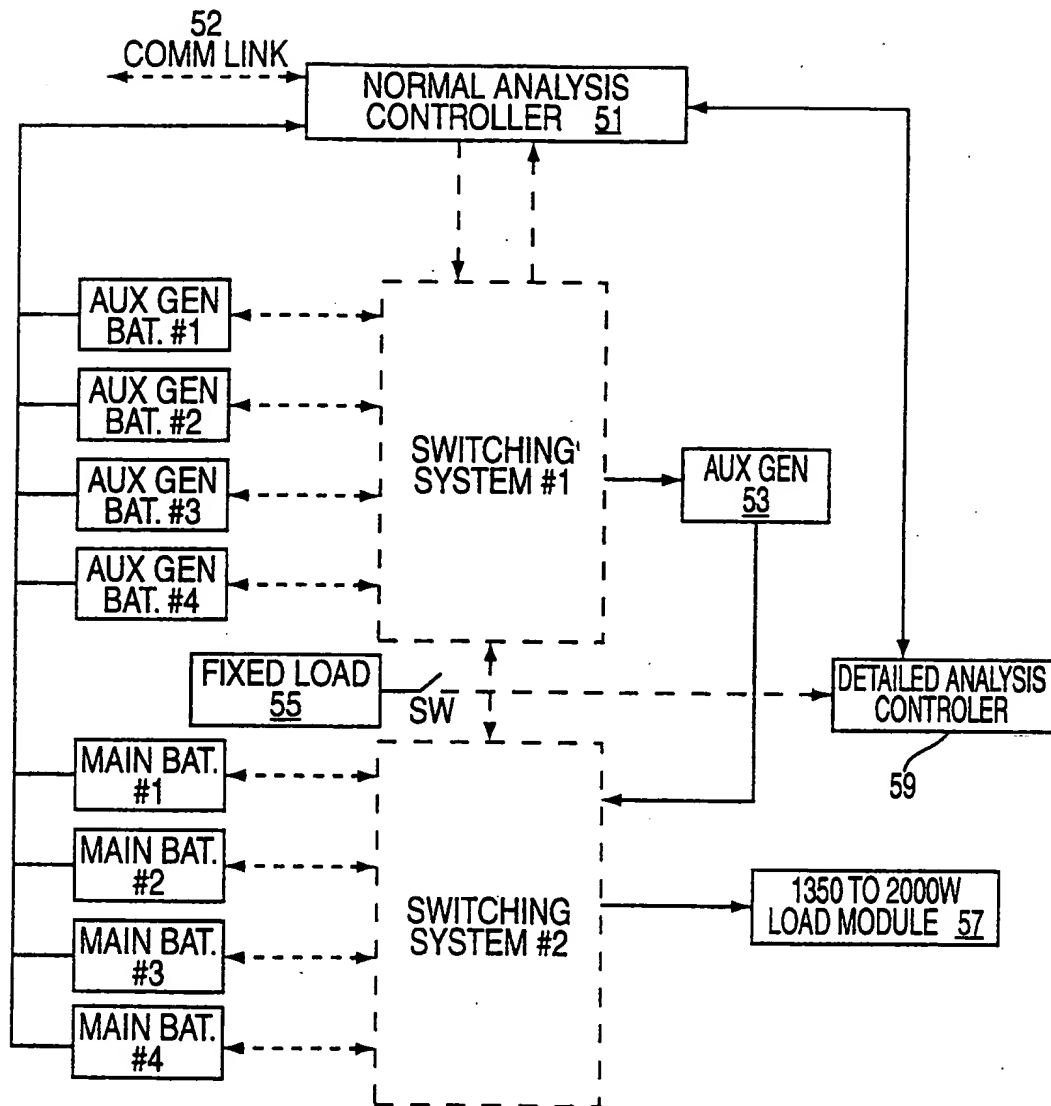


FIG. 4

8/8



BATTERY SYSTEM BLOCK DIAGRAM

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/22962

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H02J 7/00

US CL : 320/120, 122, 132, DIG.21; 324/430, 431, 433, 434

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 320/120, 122, 132, DIG.21; 324/430, 431, 433, 434

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPTO - WEST, EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US 5,955,869 A (RATHMANN) 21 September 1999 (21.09.99), whole disclosure.	1-37
Y	US 5,808,445 A (AYLOR et al) 15 September 1998 (15.09.98), whole disclosure.	1-37
Y	US 5,710,503 A (SIDERIS et al) 20 January 1998 (20.01.98), whole disclosure.	1-37
A,P	US 5,945,808 A (KIKUCHI et al) 31 August 1999 (31.08.99), whole disclosure.	1-37
A,P	US 5,886,499 A (HALL) 23 March 1999 (23.03.99), whole disclosure.	1-37
A,P	US 5,883,496 A (ESAKI et al) 16 March 1999 (16.03.99), whole disclosure.	1-37

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*G*	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
03 NOVEMBER 1999

Date of mailing of the international search report
07 FEB 2000

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Authorized officer
PIA TIBBITS

Facsimile No. (703) 305-3230

Telephone No. (703) 308-7305